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Pooled analysis of 1-year recall data from three root canal treatment outcome studies undertaken using cone beam computed tomography

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Abstract

Aim To provide an estimate of the proportion of successful outcomes of primary and secondary root canal treatments (retreatments) determined by periapical radiographs and cone beam computed tomography (CBCT), a pooled analysis of the data collected from three previous prospective clinical outcome studies was undertaken.

Methodology The analysis pooled the 1-year results for 354 teeth, including 123 primary treatments and 231 retreatments. All root canals were instrumented with ProTaper Universal and filled using a warm vertical condensation technique. Comparisons of favourable results between root canal treatments and retreatments and between different tooth types were made using chi-square/Fisher's exact test.

Results The overall percentage of favourable results was 91% using periapical radiographs and 80% for CBCT ($P<0.001$). With CBCT, the percentage of favourable results for primary treatments (84.7%) was not significantly different ($P=0.316$) from that of retreatments (77.9%). When assessed by tooth group, the overall percentage of favourable results with CBCT was 75.5%, 90.6% and 91.1% for molar, premolar and anterior teeth, respectively. When CBCT is used to assess the outcome, the proportion of favourable outcomes in molars was significantly lower than that of premolars and anterior teeth ($P<0.05$). Teeth with root fillings terminating more than 2 mm short of the radiographic apex had less favourable outcomes (73%) compared to long (83%) and adequate root filling length (84%).

Conclusions The proportions of favourable outcomes of primary root canal treatments and retreatments assessed with CBCT were lower when compared to periapical radiographs, and also lower than those historically reported by periapical radiograph-based outcome studies. Considering the very high favourable outcome of anterior teeth and premolars compared to molar teeth, future outcome studies assessing the effect of new materials and techniques on the outcome of root canal treatments should be based on pre-operative and post-operative CBCT images, and focus on molar teeth.

Introduction

Root canal treatment aims to prevent or eliminate apical periodontitis and maintain tooth function (Ørstavik & Pitt Ford 2008). The reported success rates for root canal treatment range from 31% to 100% (Ng *et al.* 2007). The persistence of microbial flora within the root canal space is regarded as the most common cause of failure of root canal treatments (Nair *et al.* 1990b, Sundqvist *et al.* 1998). When primary root canal treatment fails, secondary root canal treatment (retreatment) is often regarded as the most appropriate treatment option (Wenteler *et al.* 2015). Technical and therapeutic challenges during retreatment are often different from those encountered during primary treatment (Ng *et al.* 2008).

Evidence-based knowledge on root canal treatment outcomes enables clinicians to inform patients about the prognosis of the various treatment options available. Teeth presenting at 1-4-year recall with absence of clinical symptoms combined with radiographic evidence of a normal periodontal ligament space around the roots are regarded as successful. Conversely, the emergence of a new radiolucency or the persistence of a pre-existing radiolucency indicate an unsuccessful outcome (European Society of Endodontology 2006), resulting in an indication for clinical intervention.

Until recently, the radiographic assessment of the outcome of root canal treatment was based solely on the interpretation of two-dimensional (2D) periapical radiographs (Tyndall & Rathore 2008). The 2D nature of radiographic images, geometric distortion and anatomical noise limit the diagnostic accuracy of periapical radiographs in assessing periapical radiolucencies (Patel *et al.* 2009).

Several clinical studies have revealed a greater prevalence of apical periodontitis with three-dimensional cone beam computed tomography (CBCT) imaging compared to periapical radiography (Abella *et al.* 2012, Patel *et al.* 2012a, Cheung *et al.* 2013). Pope *et al.* (2014) suggested that the association of changes in CBCT signs with development or healing of periapical disease still needed clarification. A recent study on human cadavers using histopathology as the reference standard confirmed the superior accuracy of CBCT compared to periapical radiographs (Kanagasingam *et al.* 2017). Outcome studies using pre-operative and post-operative CBCT have shown a lower success rate of root canal treatment at follow-up when assessed with CBCT (Patel *et al.* 2012b, Liang *et al.* 2013, Metska *et al.* 2013, van der Borden *et al.* 2013, Davies *et al.* 2016, Al-Nuaimi *et al.* 2017).

A pooled analysis was performed using the data obtained from three prospective clinical trials undertaken at King's College London Dental Institute. The aim was to provide a broader dataset to estimate the proportion of successful outcomes of root canal treatments and retreatments when assessed by CBCT, and also to investigate the degree of success according to the tooth type.

Materials and Methods

Selection criteria

Data collected from three previous prospective clinical outcome studies were pooled, including one study on primary root canal treatments (Patel *et al.* 2012b) and two retreatment studies (Davies *et al.* 2016, Al-Nuaimi *et al.* 2017). Ethical approvals for the three studies were granted by the Guy's Research Ethics Committee, Guy's and St Thomas Hospital National Health Service Trust (National Research Ethics Service, England), the NRES London Bridge and Dulwich Research Ethics Committees, and the NRES West-London Research Committee. Patient information sheets were provided, and informed verbal and written consent was obtained from all patients enrolled in these studies prior to their treatment.

Inclusion and exclusion criteria

All patients were examined clinically and radiographically before inclusion. The inclusion criteria for the primary treatment study (Patel *et al.* 2012b) and retreatment studies (Davies *et al.* 2016, Al-Nuaimi *et al.* 2017) have been described. Common exclusion criteria were pregnant women, immunosuppressed patients, teeth with periodontal probing depth more than 3 mm and unrestorable teeth.

Data from 123 teeth (99 patients) with primary root canal treatment, and 238 teeth (208 patients) with root canal retreatment were available. In the retreatment sample, 7 teeth (6 patients) were included in both retreatment studies, therefore, those teeth were included only once in the pooled analysis. Finally, the pooled cohort consisted of 354 teeth in 301 patients. Eight patients in the retreatment sample had clinical complications and underwent endodontic surgery (n=7) and extraction (n=1) before the 1-year recall. Those patients were excluded from the radiographic outcome assessment because no post-operative CBCT scans were taken but they were classified as clinical failures.

Radiographic technique

Digital intraoral periapical radiographs (PA) and CBCT scans for all cases were taken pre-operatively (T0) and at approximately twelve months after treatment (T12) as described previously (Patel *et al.* 2012b, Davies *et al.* 2016, Al-Nuaimi *et al*. 2017).

Clinical intervention

All primary root canal treatments were completed in a single session, while the root canal retreatments were completed in two treatment sessions with an inter-appointment calcium hydroxide medicament. All treatments were carried out using a standardised protocol. Root canal treatment and retreatment procedures were described previously (Patel *et al.* 2012b, Davies *et al.* 2016, Al-Nuaimi *et al.* 2017). All procedures were performed under rubber dam isolation with the aid of dental operating microscopes (3 step entrée Dental Microscope, Global, St Louis, Missouri, USA). Briefly, stainless steel K-Flexofiles (Dentsply Sirona, Ballaigues, Switzerland) were used to negotiate the canal to its provisional working length. In root canal retreatment cases, Gates-Glidden burs and hand files (Hedström and K-Flexofiles, Dentsply Sirona) were used to remove the existing gutta-percha, and chloroform was used as a solvent when required. A crown-down technique with ProTaper Universal nickel-titanium rotary instruments (Dentsply Sirona) was used to prepare the root canals. The canals were continuously irrigated with 1-2% sodium hypochlorite during the procedure and the irrigant was replenished every 3-4 min. A penultimate irrigation with 15% or 17% ethylenediaminetetraacetic acid (EDTA) was undertaken followed by a final irrigation with sodium hypochlorite. The irrigant was ultrasonically activated for 1 minute. All canals were filled with gutta-percha (Dentsply Sirona) using a warm vertical condensation technique. Permanent glass ionomer (Fuji IX glass ionomer cement, GC Corporation, Tokyo, Japan) or composite resin (Herculite Ultra, Kerr Corporation, Orange, California, USA, Ceram X Duo, Dentsply Sirona) was then used to immediately restore the teeth. Where indicated, teeth were restored with cuspal coverage restorations as soon as feasibly possible after root (re)treatment had been completed.

Outcome assessment

Patients were reviewed 12 months after the completion of treatment (T12). The treatment outcome was determined by clinical findings and radiographic examinations as described previously (Patel *et* *al.* 2012b, Davies *et al.* 2016, Al-Nuaimi *et al.* 2017). At T12, the presence/absence of pain, swelling, tenderness to percussion or palpation were recorded. The radiographic assessment was carried out by a consensus panel consisting of two pre-calibrated experienced endodontists. The consensus panel assessed the images of the 2 radiographic methods using a six-point classification to record the outcome of the treatment (Patel *et al.* 2012b) (Table 1).

The outcomes were classified as follows:

- healed- if there was an absence of periapical radiolucency (i.e. outcome 5 and 6),

- healing (favourable)- if there was a reduction in size or complete absence of periapical radiolucency (i.e. outcome 4-6),

- failed (unfavourable)- when a periapical radiolucency appeared subsequent to root canal treatment, or a pre-existing periapical radiolucency remained unchanged or increased/enlarged in size (i.e. outcome 1-3).

The whole tooth was used as a unit of evaluation. Multi-rooted teeth were assessed according to the root with the worst diagnostic outcome.

Lengths of root fillings were measured on CBCT (coronal and sagittal) images using the magnifying lens of the CBCT software (I-Dixel, J Morita) and dichotomised as 'adequate' (0–2 mm short of the radiographic apex) and 'inadequate' [short (>2 mm short of the radiographic apex) or long (beyond apex)].

Data analyses

Univariate analysis was used to analyse the study data descriptively using percentage frequencies. The McNemar's test was used to compare the treatment outcomes determined by PA and CBCT imaging. Chi-square (χ^2) tests were used to compare the outcome according to the treatment modality (primary treatment versus retreatment). The difference in treatment outcomes between anterior, premolar, and molar teeth was analysed statistically using a chi-square/Fisher's exact test. The association between the outcome and the apical extension of root filling was determined using a chi-square/Fisher's exact test. The proportion of favourable outcome in maxillary and mandibular molars was compared using a

Z test for proportions. IBM SPSS software (version 23, IBM, Armonk, New York, USA) was used to perform all statistical analyses. The level of significance was set at α=0.05.

Results

The teeth were classified according to pre- and post-operative variables as shown in Table 2. In total, 354 teeth (301 patients) were included in this pooled study, of which 123 teeth (99 patients) were primary treatments and 231 teeth (202 patients) were retreatments. The sample included 45 anteriors (13%), 64 premolars (18%), and 245 molars (69%). More teeth were located in the maxillae (56%) than in the mandible (44%). The distribution of teeth according to the tooth type is shown in Figure 1.

Eight out of the 354 teeth were classified as clinical failures due to the development of clinical symptoms between T0 and T12. After twelve months (T12), 346 teeth in 293 patients (65% female and 35% male) were reviewed clinically and radiographically. The overall recall rate was 85% for teeth and 82% for patients. The average age of patients was 42 years. Three-hundred and twelve teeth had received full cuspal coverage restorations within 1-2 months of completion of the root canal (re)treatment and 21 teeth had been restored with plastic restorations.

At T12 recall, all teeth with primary root canal treatment were asymptomatic, while 17 teeth in the retreatment sample had clinical signs and/or symptoms of apical periodontitis. Table 3 shows the distribution of outcome diagnosis based on the radiographic assessment. The overall percentage of favourable outcomes was 91% and 80% as assessed by PA and CBCT, respectively (McNemar's test, P<0.001) (Table 4). For the primary root canal treatment sample, the favourable outcome percentages were 95.1% and 84.7% as assessed by PA and CBCT, respectively (McNemar's test, P=0.001). In the retreatment sample, the favourable outcomes were 88.7% and 77.9% as assessed by PA and CBCT, respectively (McNemar's test, P<0.001). With CBCT there was no significant difference (χ^2=2.224, P=0.136) between the favourable outcome percentages after primary treatment and retreatments, with an odds ratio [OR] of 0.645 (95% confidence interval [CI]: 0.361, 1.151). Table 4 lists the percentages of favourable, unfavourable and healed outcomes in the pooled sample including the 8 teeth that required further intervention prior to the 1-year recall.

With pre-operative CBCT scans, apical radiolucencies were observed in 58.5% of the teeth in the root canal treatment sample, and in 86.6% of teeth in the retreatments sample compared to 39% and 64.1% on PA, respectively. In the primary treatment sample, CBCT showed that the favourable outcome for teeth that presented without and those with pre-operative periapical radiolucency was similar (82.4% and 86.1%, respectively, χ^2=0.323, *P*=0.570) with an odds ratio of 0.75 (95% CI: 0.282, 2.010). In the retreatment sample, the favourable outcomes of CBCT-determined teeth with the absence of pre-operative radiolucency (93.5%) were significantly more numerous than those of teeth with pre-operative radiolucency (75.5%) (Fisher's exact test, *P*=0.021) with an odds ratio of 4.7 (95% CI: 1.083, 20.438). In the pooled sample, the chi-square test revealed no significant association between the treatment outcome and the pre-operative apical status (χ^2 =2.721, *P*=0.099) with an odds ratio of 1.788 (95% CI: 0.890, 3.591). The outcomes of teeth presenting with and without pre-operative periapical radiolucency are shown in Table 5. Fifteen percent of the 98.7% successes by PA for teeth with healthy periapex were undiagnosed failures when CBCT was used for the assessment, while 51% of the 70 failures by CBCT were diagnosed as healthy by PA (Table 5).

With periapical radiography, there was a lower favourable outcome in molar teeth (90.2%) compared to anterior and premolar teeth (92.7%), however, the difference was not significant (χ^2=0.554, *P*=0.453). With CBCT, molar teeth had an overall favourable result of 75.5% (76% for primary treatments, and 75.3% for retreatments) and were less successful than anterior and premolar teeth, which had a favourable result in 91.1% (*P*=0.019) and 90.6% (*P*=0.009), respectively. Within the pooled sample, molar teeth (75.5%) were less successful than anterior teeth and premolars (90.8%) pooled together (χ^2 =11.154, *P*=0.001). Twenty-one percent of the 105 molars with healthy periapex by PA were undiagnosed failures when assessed by CBCT, while 55% of the 60 failures detected by CBCT were diagnosed as healthy by PA (Table 5). There was no significant difference in the outcome between maxillary and mandibular molar teeth (Z score= -1.213, *P*=0.226). All failures in premolars occurred in the retreatment sample. The favourable and unfavourable outcomes according to tooth type are presented in Table 4.

In the pooled sample, 80% of the teeth with inadequate root filling length (short [73%], long [83%]) and 84% of the teeth with adequate root filling had favourable outcomes. Molar teeth had a higher probability of inadequate apical extent of root filling than anteriors and premolars. Chi-square/Fisher's exact tests of the pooled sample (Table 6) identified no significant differences in the proportion of favourable outcomes, between teeth with adequate and inadequate root filling length. However, the proportions of favourable outcomes in the primary treatment sample (P=0.001) and pooled sample (P=0.049) were significantly reduced in cases with short root fillings.

For the three pooled studies, the Cohen kappa values for intra-consensus panel agreements reported on outcome diagnosis ranged between 0.61 to 0.78 using periapical radiography and from 0.66 to 0.92 using CBCT, indicating substantial to almost perfect agreement (Landis & Koch 1977). The inter-examiner agreements between all the examiners of the pooled studies ranged from 0.44 to 0.84 using periapical radiography and from 0.71 to 1 using CBCT (Table 7).

Discussion

The results of the analysis of the pooled data of 354 teeth revealed that molar teeth had an overall percentage of favourable results of 75.5% (76% for primary treatments, and 75.3% for retreatments) and were less successful than anterior (91.1%) and premolar (90.6%) teeth when assessed with CBCT. The percentage of healed and healing molars were respectively 24% and 15% less when assessed with CBCT compared with periapicals.

The three studies in this pooled analysis were under the management of the same research and clinical team. They used similar treatment protocols and recall times and adopted the same radiographic assessment criteria. Pre-operative and post-operative scans were taken using the same CBCT scanner (3D Accuitomo, J Morita, Kyoto, Japan). However, the potential for clinical heterogeneity due to variation in study characteristics such as experience of operators (specialists, postgraduate students), individuals in the studies (age, gender, baseline severity of disease), intervention (primary treatment, retreatment), and location of the study (private practice, University Hospital) was limited by use of a standardised treatment protocol. In order to overcome the limitations of the pooled analysis and to avoid losing much information, a systematic review including more studies from other research groups addressing the outcome of root canal treatments using CBCT was attempted, however, this was not possible because important data were missing and attempts to contact the authors of the publications were unsuccessful.

The higher failure rate in molar teeth compared to other tooth types with CBCT is in agreement with previous studies (Fernández *et al.* 2013, Gomes *et al.* 2015) using CBCT imaging at recall but not at baseline. Conversely, other studies which have used periapicals to compare success rates for different tooth type show a higher success rate for molars compared with premolars (Hoskinson *et al.* 2002), and incisors and canines (Liang *et al.* 2011, Ng *et al.* 2011). The differing results of these studies could be attributed to the limitations of periapicals to diagnose apical periodontitis in the posterior maxillary region due to superimposition of roots with each other and other structures, such as the maxillary sinus and the zygomatic arch (Ørstavik & Larheim 1998, Low *et al.* 2008, Shahbazian *et al.* 2015). In the posterior mandibular region, the thick overlying cortical plate of the mandible may also cause anatomic noise and obscure the area of interest (Patel *et al.* 2009, 2015). Cheung *et al.* (2013) found a substantial disagreement between PA and CBCT for assessing the presence/absence and size of periapical lesions of molar teeth and highlighted the increased possibility of underestimating the number of lesions if periapical radiograph was the only means to evaluate the outcome of root canal treatment.

Lower success rates may be explained by the complex root canal anatomy of molar teeth compared to single-rooted teeth (Cleghorn *et al.* 2006, de Pablo *et al.* 2010) that presented a greater challenge to shape, disinfect and fill.

The pooled favourable outcome observed by CBCT (80%) was significantly lower compared with that observed by periapical radiography (91%) ($P<0.001$). Overall CBCT detected 21.1% more post-treatment periapical lesions than PA which is broadly in agreement with the findings of other studies that also used pre-and post-operative CBCT scans to assess the outcome of root canal treatment (Liang *et al.* 2013, van der Borden *et al.* 2013). Based on PA results, the favourable outcome of the present pooled data (91%) was comparable to that obtained (93.9%) by Friedman *et al.* (1995), including both treatment and retreatments cases. The discrepancy between the observations made by PA and CBCT could be attributed to the more accurate detection of apical periodontitis on CBCT images due to the ability of CBCT scans to provide a three-dimensional reconstruction of an anatomic area while minimising anatomical noise from the overlying structures (Patel *et al.* 2012b). Based on the above findings, the complete absence of a periapical lesion on PA does not guarantee that the lesion is not present which could lead to overestimation of the successful outcome of the treatment. In contrast, CBCT can provide a more accurate understanding of the outcome of root canal treatment and, therefore, re-evaluation of the success of root canal treatment with long-term follow-up studies using CBCT is needed (Wu *et al.* 2009, Kanagasingam *et al.* 2017).

With CBCT, the percentage of favourable results for primary treatments (84.7%) was not significantly different (*P*=0.136) from that of retreatments (77.9%), which is in agreement with other studies based on periapical radiographs (de Chevigny *et al.* 2008a, 2008b, Ng *et al.* 2011). In a well-controlled prospective study, Ng *et al.* (2011) reported comparable success rates between initial root canal treatment and retreatment using strict criteria (83% vs 80%) or loose criteria (89% vs 86%), respectively (Ng *et al.* 2011). Similarly, in the Toronto study, the pooled outcome of primary (de Chevigny *et al.* 2008a) and root canal retreatment (de Chevigny *et al.* 2008b) was investigated. After 4 to 6 years, 86% of teeth with primary root canal treatments and 83% of teeth with root canal retreatments were healed.

In this study, the interaction between the pre-operative periapical status and treatment outcome had a different effect on primary treatment and retreatment. In the primary treatment sample, the prevalence of failure of molar teeth with no pre-operative apical radiolucencies assessed with CBCT (17.6%) was higher compared with those with existing periapical radiolucency (13.9%). The difference was not significant (OR=0.75, *P*=0.570). This result is consistent with Sjögren *et al.* (1990) who reported that the success rate of primary treatments with previous apical periodontitis was as good as that without apical periodontitis (Sjögren *et al.* 1990). However, this finding contrasts with that of other studies (Hoskinson *et al.* 2002, Imura *et al.* 2007, Liang *et al.* 2012) where the presence of pre-operative apical periodontitis determined with PA was a significant predictor of treatment outcome. Unlike the primary treatment sample, the influence of periapical status on retreatment outcome was more pronounced (*P*=0.021). The favourable outcome of 93.5% for teeth retreated without pre-operative apical periodontitis, determined by CBCT, was 18% (OR=4.7) higher than in those with pre-operative apical periodontitis (75.5%). This result is in line with the finding reported by previous studies which assessed the outcome using periapical radiographs (Gorni & Gagliani 2004, Azim *et al.* 2016). The negative influence of periapical status on retreatments may be explained by the ability of bacteria in root filled teeth with persistent apical lesions, in particular, *Enterococcus faecalis,* to resist eradication by conventional root canal treatment (Nair *et al.* 1990a, Molander *et al.* 1998, Sundqvist *et al.* 1998). In addition to the intraradicular microbes, it should be noted that, in some cases, persistent lesions associated with root filled teeth may occasionally be caused by extraradicular infection, which can be a factor of root canal treatment failure (Siqueira 2001).

With regard to the apical extent of root filling, teeth with root fillings terminating more than 2 mm short of the radiographic apex had a lower favourable outcome (73%) compared to long (83%) and adequate root filling length (84%).

Interestingly, long root fillings were associated with higher favourable outcome compared with short root fillings. This is in line with the periapical radiographs findings of Ng *et al*. (2008) for teeth with pre-operative periapical lesions, in which teeth with short root fillings had the lowest success rate, taking in consideration that 77% of the teeth in the pooled sample had pre-operative periapical radiolucency detected by CBCT. It is possible that short fillings, particularly in the primary treatment group are associated with the development or persistence of small periapical radiolucencies which are not detected by periapical radiographs, whereas the presence of extruded root filling material is associated with a widening of the lamina dura that is more easily identifiable with periapical radiographs.

Conclusion

In the present study, the percentages of favourable results of primary root canal treatments and retreatments assessed with CBCT was lower than those historically reported by periapical radiograph-based outcome studies. The proportion of favourable results of primary treatment and retreatment are comparable. CBCT demonstrated more failures in molar teeth than anterior teeth and premolars compared with periapical radiographs. Inadequate root filling did not influence the outcome significantly. Considering the very high healing rate of anterior teeth and premolars, future outcome studies exploring the effect of new materials and techniques on the outcome of root canal treatments should be based on pre-operative and post-operative CBCT images and focus on the healing rate of molar teeth.

Conflict of Interest statement

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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Figure Legends

Figure 1 Teeth distribution according to the tooth type

Table 1 The outcome categories for root canal (re)treatment (Patel *et al.* 2012b)

Score	Outcome
1	New periapical radiolucency
2	Enlarged periapical radiolucency
3	Unchanged periapical radiolucency
4	Reduced periapical radiolucency
5	Resolved periapical radiolucency
6	Unchanged healthy periapical status [no radiolucency before and after root canal (re)treatment]

Table 2 Univariate distribution of pre- and post-operative variables.

Variables	Primary treatment Patel *et al.* (2012b)	Retreatment Davies *et al.* (2016)	Retreatment Al-Nuaimi *et al.* (2017)	Pooled sample
Pre-operative				
Number of patients reviewed	99	87	115	301
Mean age	44.5	39	43	42
Gender				
Male	42	29	34	105 (35%)
Female	57	58	81	196 (65%)
Tooth type				
Anterior	30	15	-	45 (13%)
Premolars	18	18	28	64 (18%)
Molars	75	68	102	245 (69%)
Tooth location				
Maxilla	67	65	66	198 (56%)
Mandible	56	36	64	156 (44%)
Pre-operative periapical radiolucency (PA)				
Absent	75	35	48	158 (45%)
Present	48	66	82	196 (55%)
Pre-operative periapical radiolucency (CBCT)				
Absent	51	12	19	82 (23%)
Present	72	89	111	272 (77%)
Post-operative				
Clinical signs and symptoms of apical periodontitis				
Absent	123	90	124	337 (95%)
present	0	11	6	17 (5%)

Table 3 Frequency distribution of outcome of treatment for each tooth in primary root canal treatment, retreatment, and pooled samples (n=346) assessed using periapical radiographs (PA) and CBCT (radiographic assessment only)

Outcome category	Primary treatment sample		Retreatment sample		Pooled sample	
	PA	CBCT	PA	CBCT	PA	CBCT
1- new lesion	1	9	0	2	1	11
2- enlarged lesion	1	5	6	17	7	22
3- unchanged lesion	4	5	11	24	15	29
4- reduced lesion	10	27	37	54	47	81
5- resolved lesion	33	35	86	97	119	132
6- no lesion before/after (re)treatment	74	42	83	29	157	71
Total	123	123	223	223	346	346

Table 4 Percentage of success rates based on clinical symptoms and radiographic examination with periapical radiographs (PA) and CBCT for each tooth type in the pooled sample (n=354)

Outcome category	Maxillary incisor/canine		Maxillary premolar		Maxillary molar		Mandibular Incisor/canine		Mandibular premolar		Mandibular molar		All cases	
	PA	CBCT	PA	CBCT	PA	CBCT	PA	CBCT	PA	CBCT	PA	CBCT	PA	CBCT
Unfavourable (1,2,3)	9	9	7	11	13	28	9	9	0	0	7	21	9	20
Favourable (4,5,6)	91	91	93	89	87	72	91	91	100	100	93	79	91	80
Healed (5,6)	79	77	82	59	79	54	91	91	70	60	74	52	79	57

Table 5 The outcome of root canal treatments according to pre-operative variables as determined by periapical radiography (PA) and CBCT

Variables	PA		CBCT	
	No. of teeth	Favourable outcome	No. of teeth	Favourable outcome
Pre-operative apical periodontitis				
Primary treatment sample				
Absent	75	98.7% (74)	51	82.4% (42)
Present	48	89.6% (43)	72	86.1% (62)
Retreatment sample				
Absent	83	98.8% (82)	31	93.5% (29)
Present	148	83.1% (123)	200	75.5% (151)
Pooled sample				
Absent	158	98.7% (156)	82	86.6% (71)
Present	196	84.7% (166)	272	78.3% (213)
Tooth type				
Primary treatment sample				
Anterior	30	96.7% (29)	30	96.7% (29)
Premolar	18	100% (18)	18	100% (18)
Molar	75	93.3% (70)	75	76% (57)
Retreatment sample				
Anterior	15	80% (12)	15	80% (12)
Premolar	46	91.3% (42)	46	87% (40)
Molar	170	88.8% (151)	170	75.3% (128)
Pooled sample				
Anterior	45	91.1% (41)	45	91.1% (41)
Premolar	64	93.8% (60)	64	90.6% (58)
Molar	245	90.2% (221)	245	75.5% (185)

Table 6 Influence of apical extension of root filling, assessed on CBCT images, on root canal treatment outcome

	Short	Long	Inadequate (short and long)	Adequate
	Favourable outcome % (n)	Favourable outcome % (n)	Favourable outcome % (n)	Favourable outcome % (n)
Primary treatment sample				
Anteriors	100 (1)	100 (5)	100 (6)	96 (23)
Premolars	100 (1)	100 (5)	100 (6)	100 (12)
Molars	53 (8)*	76 (19)	68 (27)	86 (30)
Total	59 (10)*	85 (29)	77 (39)*	92 (65)
Retreatment sample				
Anteriors	100 (1)	100 (4)	100 (5)	88 (7)
Premolars	100 (4)	100 (10)	100 (14)	84 (26)
Molars	76 (25)	79 (49)	78 (74)	77 (54)
Total	79 (30)	83 (63)	82 (93)	80 (87)
Pooled sample				
Anteriors	100 (2)	100 (9)	100 (11)	94 (30)
Premolars	100 (5)	100 (15)	100 (20)	88 (38)
Molars	69 (33)	78 (68)	75 (101)	80 (84)
Total	73 (40)*	83 (92)	80 (132)	84 (152)

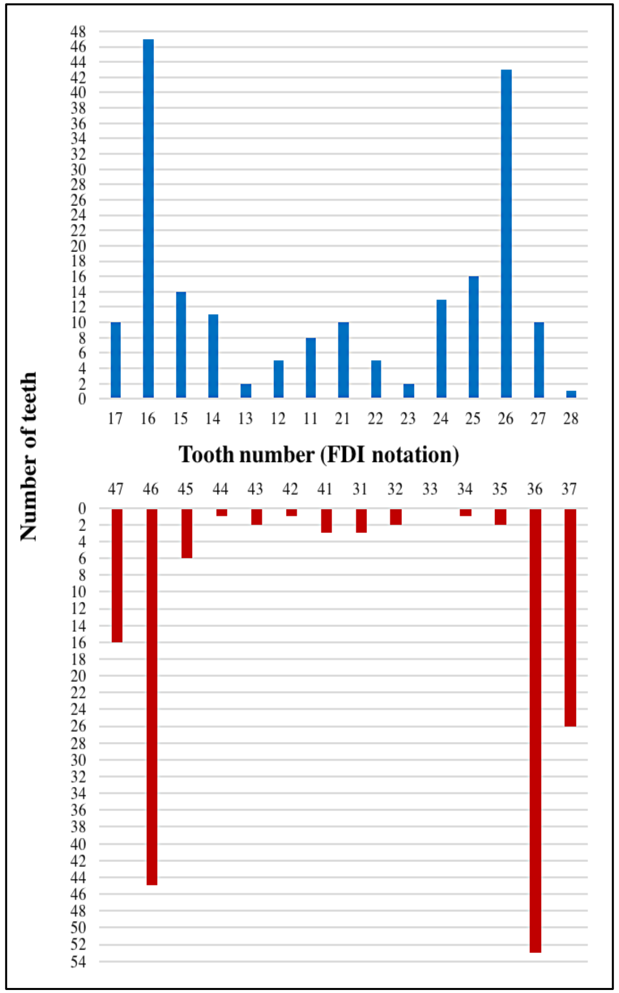
* Chi-square test indicates statistically significant difference ($P<0.05$)

Table 7 Kappa values for intra-consensus panel agreement and inter-examiner agreement on outcome diagnosis using periapical radiography (PA) and CBCT

	Intra-consensus panel agreement		Inter-examiner agreement	
	PA	CBCT	PA	CBCT
Primary treatment sample	0.74-0.78	0.86-0.92	0.44-0.84	0.73-1
Retreatment sample	0.61-0.71	0.66-0.71	0.53-0.72	0.71-0.72

0.40-0.60 moderate agreement, 0.60-0.70 substantial agreement, 0.80-1.0 almost total agreement

Figure 1


Number of teeth
48 46 44 42 40 38 36 34 32 30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
17 16 15 14 13 12 11 21 22 23 24 25 26 27 28
Tooth number (FDI notation)
47 46 45 44 43 42 41 31 32 33 34 35 36 37
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54